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Pulp Insulation for Telephone Cables *

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Pulp insulation is a new type of insulation that bas been developed to replace the well-known spirally wrapped ribbon paper insulation in certain kinds of telephone cables. It consists of a continuous pulp sleeving formed directly on the wire by a modified paper making process. The raw material for this insulation is commercial Kraft pulp and its preparatory treatment in the beaters corresponds to that given in the regular paper making process.

The machine used to apply this pulp to the wire is a modified single cylinder paper machine equipped to insulate 60 wires simultaneously. The wires are taken from the supply spools by means of flyers so as to allow the brazing of the wire on a nearly empty spool to a conveniently located full one. This gives continuous operation. The wires are fed to tbe machine through an electrolytic cleaner for the removal of residual drawing compound. The surface of the mold or paper forming mechanism is divided into 60 narrow portions in such a way as to form that many narrow sbeets continuously. The wires are brought into contact with the mold in such a way that, as it rotates and forms the sheets, a single wire is embedded in each sheet. These sheets and wires are transferred from the mold to a traveling wool blanket by the pressure of the couch roll. The traveling blanket carries the sheets and wires through the presses for dewatering and consolidating, and delivers them to the polishers where the sheet is turned down by a rapidly rotating mechanism into a cylindrical wet sleeve surrounding the wire. The moisture is driven from the wet insulation by passage through a box type electric furnace one end of which is maintained at a rather high temperature. The insulated wire is then taken up on spools ready for the twisting operation. The speed of the machine is about 130 feet per minute.

The major difficulties in the process have been overcome and the basic properties of the insulation have been determined. Equipment for the production of about 225 million conductor feet per week has been provided and the entire output of 24 and 26 A.W.G. cables is being made in pulp.

These cables are designed to the same size as the ribbon paper cables which they replace and compare favorably with them in their electrical characteristics except that the mutual capacitance is slightly higher. The impairment in transmission efficiency due to the higher capacitance is, however, more than offset by the lower cable first cost.

Standardized installation practices are followed except that a softer and more lubricating type of boiling-out compound than paraffin wax is required, particularly at low temperatures. A suitable compound has been found by adding paraffin oil to wax in varying proportions depending upon the temperature at the point of splicing.

The anticipated savings have been realized in tbe operation of the commercial units and the further expansion of the uses of this insulation is being studied.

In this paper a more complete and technical treatment of the pulp insulation development is presented tban was given in previous papers.[1]

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[1] *Bell System Technical Journal*, Vol. X, pp. 432–471, "Developments in the Manufacture of Lead Covered Paper Insulated Telephone Cable"—J. R. Shea. *Bell Telephone Quarterly*, Vol. X, No. 4, pp. 211–215, "An Important New Insulating Process for Cable Conductors"—H. G. Walker. *Bell Laboratories Record*, Vol. X, No. 8, pp. 270–278, "Pulp—The New Cable Insulation"—L. S. Ford.

Introduction

OPEN wires were almost universally used for the transmission of speech in the days when telephony was young but gradually as the need arose the art of cable making was evolved. Today, except in the rural districts, the open-wire lines have been almost entirely replaced by aerial or underground cable. The conductors in the early metal covered cables were insulated with one or two servings of cotton but in the late eighties Bell System engineers developed a spirally wrapped paper insulation so much better electrically and lower in cost that it was shortly adopted as the standard insulation for telephone cables by the growing industry. Now after some forty years of service this type of insulation is being rapidly displaced for inter-office and subscriber loop cables by a pulp insulation applied directly to the conductor by a process which brings the paper mill into the cable plant and combines the paper making and insulating operations into one process with the elimination of a number of costly intermediate steps. In addition, this process makes possible the use of a less expensive material as an insulating medium.

In order to establish a background for the logical consideration of the pulp insulation development it is desirable to cover briefly the materials, equipment and methods that have gradually been developed for the rapid application and economic use of paper ribbon insulation and indicate the limitations involved.

For many years the standard paper in this country for insulating conductors for lead sheathed telephone cables was made from a stock composed of all old rope or old rope and a small admixture of cotton, the fibres of the rope being chiefly manila from the plant Musa Textilis or hemp from the plant Cannabis Sativa. Papers of such composition, slit into long narrow strips, were applied helically around the wire to form the insulated conductor. Experience had proved them to be highly suitable as an insulating medium, both as to structural permanency and electrical characteristics and to be sufficiently flexible and strong mechanically to admit of ready application to the conductor in manufacture and to withstand subsequent handling in service. With the mounting demand for insulating papers, however, came the urge for the finding of a suitable less expensive fibre and the year 1920 saw the adoption, for the larger sizes of paper only, of a formula composed of about 40 per cent chemical wood pulp and the remainder rope stock. This wood fibre is of the spruce or other coniferous tree species prepared by the sulphate or "Kraft" process. It is required to have a high cellulose content and to be as free from water soluble salts as the best manufacturing practice will permit. Extensive tests

have demonstrated that it compares favorably in stability and permanence with the well established manila fibre. In the case of pulp insulated cable which is discussed in this paper the raw material used is 100 per cent of this wood fibre.

The present day ribbon paper insulating machine as developed by the Western Electric Company is essentially a rotatable hollow tapered spindle centrally mounted on and integral with a light weight disc about 15 inches in diameter. The wire to be insulated passes through

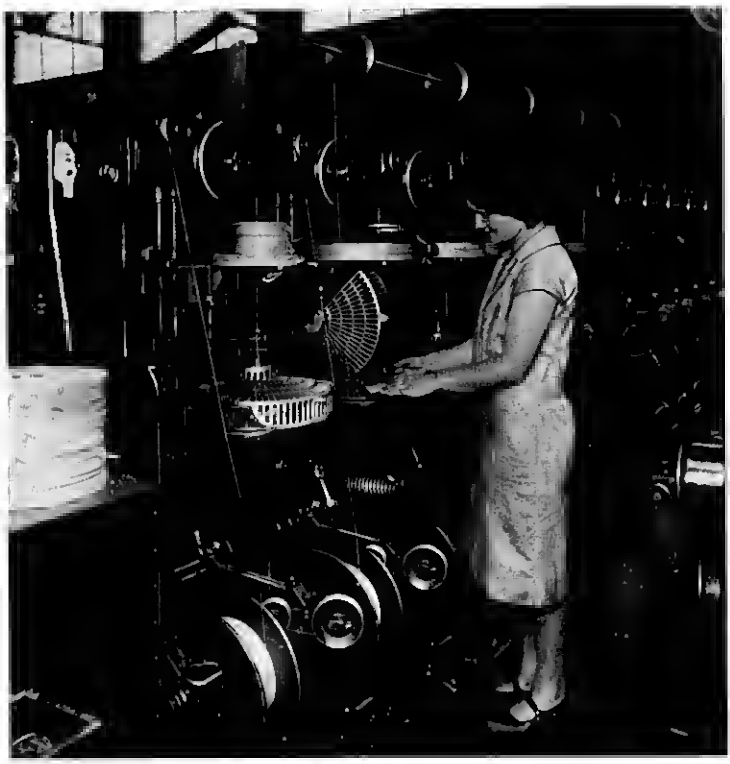

Fig. 1—Ribbon paper insulators.

the spindle over a capstan and to the take-up spool. The insulating paper wound into a pad or disc is slipped over the spindle and supported by the metal disc. This whole assembly is arranged to rotate rapidly around the wire and feed the paper ribbon from the periphery of the pad through guides so as to form a continuous spiral wrapping around the wire which is advanced at a definite speed by the capstan. The speed of rotation of the spindle is approximately 3300 R.P.M.

and the wire advances from 175 to 200 feet per minute depending on the length of wrap.

From a process standpoint manila paper was selected originally because of its strength and elasticity and in the development of equipment to serve it full advantage was taken of these two characteristics, particularly for the insulation of the finer gauges of wire. This fact tended to handicap the adaptation of cheaper papers to this purpose when the changing conditions in the paper industry made such a step desirable, since the readily available substitutes were somewhat inferior in these two respects. Studies were undertaken to modify the equipment for serving ribbon paper with the idea of adapting it for handling this paper, but with only indifferent success. The mixing of varying amounts of wood pulp with manila stock proved to be a successful solution in the case of heavier papers, but in the thinner ones the results were not satisfactory, and progress in this direction was at a standstill.

Fig. 2—General view of pulp insulating equipment. Take-up and dryer in left foreground, polishers and wet machine in right center and wire supply and pulp preparation equipment in right and background.

The Development of Pulp Insulated Wire

In line with the generally recognized need for a radical change in the insulating situation some work was initiated in 1921, with the idea of determining the possibilities of producing a continuous homogeneous paper covering directly on the wire and a scheme was worked out which

after some preliminary experiments gave sufficient promise of success to suggest the desirability of going ahead with the development of the idea and the mechanism to carry it out.

A crude paper machine of the cylinder type was built and with this the feasibility of the basic idea was demonstrated. Dryers were next improvised and sufficient wire was insulated to give a few short test cables. These, of course, were made from carefully selected insulation for only a small part of the wire made was usable. The test results on these cables were sufficiently interesting to warrant proceeding further with the project. After considerable study and experiment it was decided to build a ten-wire machine adaptable to future expansion if

Fig. 3—Wire supply and pulp preparation equipment.

the anticipated results were realized. This ten-wire machine was started up with very indifferent success in January, 1924. During that year an operating technique was gradually developed and numerous improvements made in the equipment. In 1925, a great many test cables were made and several were installed for use in the telephone plant. Experience with the ten-wire operation and product finally became so satisfactory that it was decided to expand the machine to a fifty-wire capacity and put it on as near a commercial basis as possible, in order that its operation, product and economics might be studied to better advantage. Accordingly, the necessary

auxiliary equipment was purchased and installed and the machine converted to a fifty-wire basis.

The installation was completed early in 1928 and the machine put in experimental operation about March of that year. As rapidly as possible crews were broken in and late that summer the machine was placed on a regular operating basis with three complete crews on a twenty-four-hour day and six-day week. It continued to operate on this basis until 1931, when ten more wires were added. This product was cabled into 26 and 24 A.W.G. cables on standard cabling equipment with no major difficulties and installed in commercial telephone plant by the operating companies. No serious operating trouble has developed in any of this cable.

The pulp insulated wire capacity now at the Hawthorne and Kearny plants is approximately 225 million conductor feet per week and all 24 and 26 A.W.G. exchange area cables are being manufactured from pulp insulated wire.

Process

Essentially the process consists in forming simultaneously on a modified cylinder paper machine 60 narrow continuous sheets of paper with a single strand of wire enclosed in each sheet, pressing the excess moisture from the sheets, turning them down so as to form a uniform cylindrical coating of wet pulp around the wire and then driving the water from this coating by drying at a high temperature.

The insulating material is given practically the same treatment in a beater as it would receive in paper making, but without the addition of sizing or loading. The beaten pulp is stored in a large tank from which it is pumped to a mix box for dilution with water before passing to the screen where coarse particles and lumps are removed.

For the next operation a modified paper machine of the cylinder type is used. The mixture of pulp and water is fed into the cylinder vat by gravity from the screen. The cylinder mold itself is divided into 60 narrow, uniform sections by dams or deckels on the surface of the wire cloth covering. The bare conductors coming to the machine are guided so that one conductor passes around the mold in each of the sections. As the mold is rotated in the water suspension of pulp in the vat, a narrow continuous sheet of paper with a conductor embedded in it is formed in each section by the simple paper making process of straining the fibres from the suspension as the water flows through the fine wire cloth covering the mold, under the slight head maintained outside the mold. These sheets are transferred from the mold to a woolen felt by the pressure of a couch roll and carried by it through two presses which take out a considerable part of the water

and leave the material in shape to be turned down to the final form. This is done by passing the conductors embedded in the narrow sheets through individual polishers which turn the wet sheet down into a uniform covering of a size determined to a large extent by the amount of pulp deposited in the sheet. These polishers are simply rapidly rotating heads carrying three specially shaped blades so arranged that one blade deflects the traveling wire and sheet from a straight line against the other two with a pressure controlled by the tension on the wire. The wet cylindrical insulation is then dried to about a 9 per cent moisture content by a single passage through a horizontal electric furnace 26 feet long the wet end of which is maintained at a temperature of about 1500° F. and the dry or tempering end at something under 800° F. The wires are carried through the drier by a rotary pulling mechanism designed to minimize the crushing or flattening of the dried insulation. This device delivers the finished product to the take-ups for spooling. The machine is operated at about 130 feet per minute.

Considerable amounts of water are used in the process, for in this, as in all paper making processes, water acts not only as a carrier for the fibres, but it forms some sort of a loose chemical or mechanical combination with them in the beater which is one of the principal factors in determining the final characteristics of the material. The approximate fibre concentrations at the various steps of manufacture are as follows:

Beater	3.5–4%
Storage	1.3%
Screen	0.07%
Cylinder Vat	0.05%
Polishers	28%
Completed Insulation	91%
Finished Cable	100%

Some Problems Involved

In theory the whole process is remarkably simple, but from the practical standpoint, many intricate problems had to be solved before satisfactory operation was possible. In some cases it was rather difficult to segregate the problems for study as there were so many variables involved. Gradually, however, these details have been cleared up and today operation is quite satisfactory. A brief survey of some of the more important problems and their solutions may be of interest.

Continuous Operation

It is quite essential, from an economic standpoint, that the machine should operate continuously. The fact that the supply spools carry

only a limited amount of wire necessitated the working out of a dependable means for shifting from an empty to a full spool without a shutdown or break in conductor or insulation. This is accomplished by taking the wire off over the head of a spool by means of a flyer and brazing the inner end of the wire on one spool to the outer end of the next. Again in spooling the finished material at the dry end, the wire must be transferred from a full spool to an empty without interfering with the operation of the machine. This has been taken care of very

Fig. 4—Changing spools at supply end.

simply by providing two spool positions for each wire with a simple manual means of shifting from one to the other.

Broken Wires

In spite of all the care that can be exercised, wires break at times and as a matter of economy, methods of restringing the broken wires with the machine in operation had to be worked out. Continuous six-day week operation is now possible without shutdowns except for the midweek clean-up.

Wire Cleaning

The supply wire comes to the machine on spools. It is spooled on the wire drawing machine and annealed on the spool. The surface of this wire, annealed with the drawing compound on it, seems to act somewhat as a repellant to wet pulp and causes a ragged, broken insulation. This is probably due to a surface tension effect. This action caused considerable trouble in the early stages of the work as the blame was placed on polishers, pulp, felts, or anything but the wire surface. Finally it became apparent that the surface condition of the wire was a large factor and the trouble was eliminated by passing all the bare wires through an A.C. electrolytic cleaner between the supply stand and the wet machine.

Tensions

Fine gauge copper wire is soft and easily stretched, pulp insulation in the wet form possesses very little strength, and in the dry form its elongation is much lower than spirally wrapped ribbon insulation; hence it is necessary at every step in the process to maintain minimum tensions in order that the wire may not be stretched and the insulation opened. Devices have been developed that are quite efficient in holding tensions within the safe range.

Pick-Up

In the early operating stages the pick-up from the mold was at times ragged and uneven and the sheet formation not all that could be desired. It was found that these conditions could be materially improved by the addition of a very small amount of soap to the pulp suspension immediately before it reaches the machine.

Polishing

In connection with the operation of polishing the sheet down to a circular insulation it has been found that a water content of approximately 72 per cent is preferable to a dryer or wetter sheet as it seems to felt down and form a more homogeneous insulation. The polisher itself has required a considerable amount of development work to insure a continuous uniform product and avoid stripping when a lump or break in the sheet occurs.

Drying

Several methods of drying pulp insulation were given a thorough trial but a completely satisfactory drier did not prove a simple thing to find. Finally, however, it was discovered that very rapid drying caused less shrinkage than slower drying, and so resulted in a less dense insulation. As a low density insulation is very desirable

electrically, this was the deciding factor in adopting high temperature radiant heat drying and experience has amply justified the decision.

Operation

The development of operating technique and methods offered some difficulties as the process is neither wholly paper making nor wire handling. Preliminary methods were worked out by engineers on the machine. Then regular operators were recruited for the most part from the operating organization and broken into the work. Most of

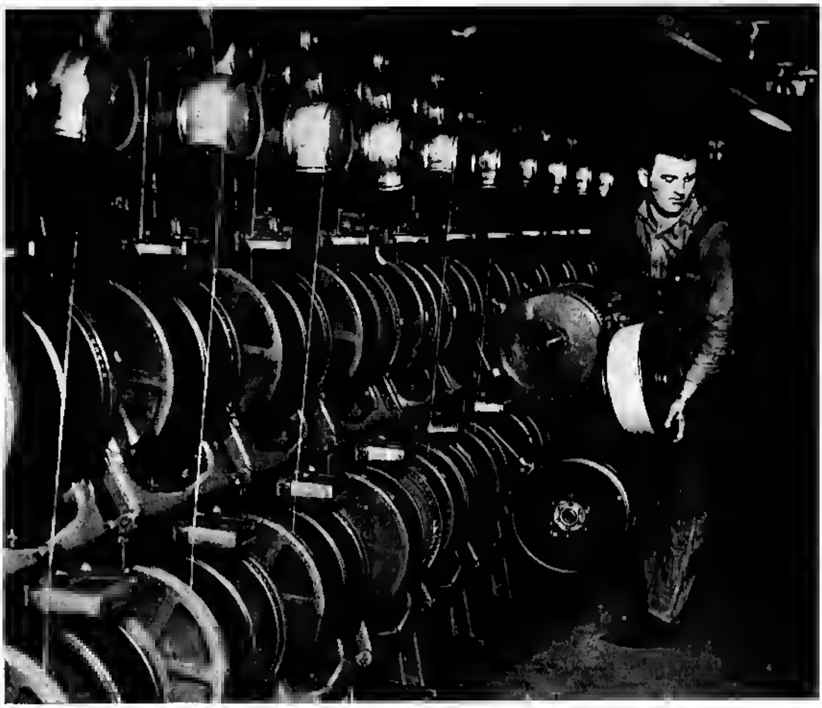

Fig. 5—Changing spools and take-up.

them had never seen a paper machine before but they became very efficient in a surprisingly short time and there have been no prejudices acquired on regular paper machines to overcome.

Making Narrow Ribbons

The question of making narrow uniform ribbons has given considerable trouble. The most satisfactory solution of this problem to date is the use of deckels or dams painted on the mold mechanically at spaced intervals. Apparently very good life can be expected from such a mold.

Defective Wire

It is necessary to mark defects in the completed wire by placing a white tag in the winding in order that repairs may be made by the twister operators, as there is no opportunity to make them at the pulp machine take-ups. Short breaks in the insulation were often passed

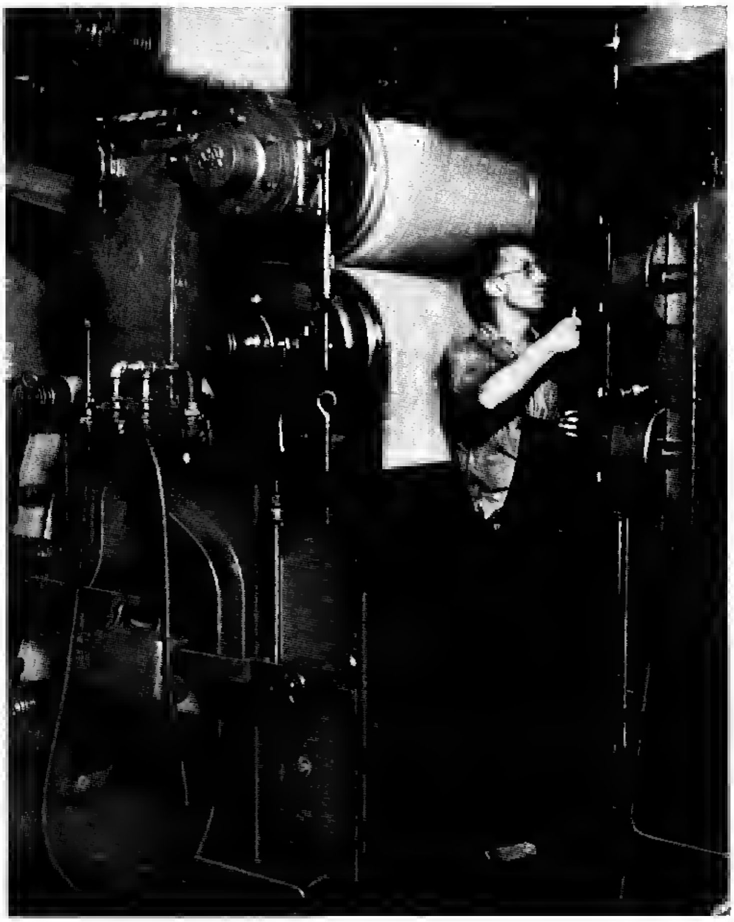

Fig. 6—Stringing in a wire at polishers.

unnoticed by the operators so a bare wire detector was put in which sounds an alarm, indicates the spool position by a light and records the break by number on a position counter and on a master counter. If any one spool shows excessive defects it is rejected.

General Physical Characteristics

Pulp insulation is a new product and has certain inherent characteristics. These characteristics may be modified somewhat by choice of materials and methods of manufacture but they cannot be entirely controlled. A brief survey of these characteristics may be of interest to give a better picture of the possibilities and limitations of the product. This survey covers only 24 and 26 A.W.G. wire as these are the sizes which have been run almost exclusively to date. It should be noted, however, that wires ranging in a size from 19 to 28 A.W.G. have been covered successfully.

Some of the physical characteristics of the insulation are shown below in tabular form giving the possible range of values obtainable. They are controlled by the beating of the pulp, the amount of pulp fed to the machine, the dryness of the sheet in the polishers and the speed of drying.

Diameter of Insulated Wire, Inches.......	0.030 to 0.050 for 24 A. W. G.
	0.026 to 0.040 for 26 A. W. G.
Weight of Dry Pulp, Grams per Foot.....	0.045 to 0.12 for 24 A. W. G.
	0.040 to 0.095 for 26 A. W. G.
Density—Ratio of Fibre to Total Volume..	35% to 55%—Independent of Gauge.

The tensile strength and flexibility of the insulation can be varied through rather wide limits by different treatments during manufacture. The elongation is quite comparable to that of ordinary paper and is not susceptible of much variation. The insulation is made sufficiently strong and flexible to withstand the various operations incident to cable fabrication and subsequent handling yet not so tough that it cannot be readily removed from the wire at the point of splicing.

The surface of the insulation has a rather rough blotting paper appearance, though some variation is possible by changes in the beating. The cross-section is circular with the conductor in the center in the ideal case, but because of limitations imposed by practical operating considerations there is a tendency toward some eccentricity and flattening of the insulation.

Pulp Insulated Cables

Design

The smallest wires now used in commercial telephone cables are 24 and 26 A.W.G. and it has been found that pulp is particularly suitable for insulating such fine wires. Here it is in direct competition with non-wood content strip paper that has been giving satisfactory

quality performance. To displace the old standard, pulp must meet this competition and give a greater return for the money invested.

Telephone cable circuits are normally subjected to only a low dielectric stress which permits their being placed in close proximity to one another and the primary requirement of the insulation is that it be distributed in a thin layer of uniform application, with the wire well centered so that each conductor when packed into a cable is completely insulated from its neighbors throughout its length. The mean radial thickness of the pulp insulation for the 26 A.W.G. wire which is in common use is less than one hundredth of an inch and for 24 A.W.G. which is the next larger size of wire usually used for telephone cables this value is about 0.011 inch. The pulp is prepared and applied to the conductor in such a manner that the fibres pack together to form a cover with sufficient strength and elasticity to withstand the handling the insulated wire must receive and yet be as light as possible in weight per unit volume in order to obtain the best electrical characteristics.

At the time this development was started 24 A.W.G. wire was the finest regularly used and the earlier pulp cables were confined to this gauge. Pulp insulated wire is structurally more like textile insulated wire than air-spaced paper ribbon insulated wire. The insulation is firm with no appreciable air gap between it and the wire, and bundles of wires nestle together differently when grouped into a given space. Furthermore, it was found that when pairs of conductors were stranded together in the usual manner of concentric layers each reversed in direction, the unit thus formed was considerably less flexible than the present standard construction. This is apparently caused by the greater frictional resistance between layers sliding over each other as the cable is bent, thus causing sharp kinks for even moderate bends. While this feature is less pronounced for small cables, it is, of course, objectionable and an improvement in the handling qualities is effected by stranding several layers in the same direction rather than employing the single reverse layer construction. For the large size cable, a design whereby the pairs are first grouped into units of fifty-one or one hundred and one, all the pairs in these units being stranded in the same direction and the units then stranded together into a cable, gives a construction which seems to offer the most satisfactory arrangement. Thus, for example, a 1212 pair cable is made up of 12 units of 101 pairs each, arranged with four units in the center and eight in a surrounding layer, and an 1818 pair cable is laid up with two units in the center surrounded by six units in the first layer and ten units in the second layer. Fig. 7 shows a short section of 1818 pair 26 A.W.G. cable with the units separated. One might expect these rather large

units would not group themselves together into a circular shape without poor utilization of the space they occupy but it has been found that by properly constructing the individual units and by suitable arrangement of the cable layup, a cross-section is obtained with the groups keystoning together nicely and presenting no noticeable voids.

The cable core must also have a certain firmness or density to give

Fig. 7—Section of 1818 pair 26 A.W.G. cable showing units separated.

the best support to the sheath and insure satisfactory handling as the cables are being installed. With ribbon paper insulation the ratio of the amount of insulation to the non-copper space in a cable was found to be a fairly good criterion of the firmness required. With the fundamentally different physical characteristics of the pulp insulated wire this relationship was altered and experimental trials were therefore necessary to determine the approximate size of pulp insulated

wire most suitable for the space it was to occupy in cable form. There is some latitude here in the distribution of a given amount of fibre but taking into account both the mechanical and electrical requirements, the diameter for the insulated conductor finally selected as the most satisfactory for the series of standard cables of 24 A.W.G. was 0.041 inch and for 26 A.W.G.—0.033 inch, and the aim in manufacture is to produce an insulation as uniformly close to these dimensions as possible. These diameters are measured by a volume displacement method. Short samples, as representative as possible of the wire under consideration, are inserted for a given distance into a small bore tube of mercury and the displacement noted. The gauge is calibrated so that mean diameters are read directly on the scale.

The above specific sizes of pulp insulated conductors apply only to cables designed for a particular set of characteristics. As in the case of ribbon paper cables, the amount of insulation for a given gauge of conductor may be varied within reasonable limits, so as to produce cables of other characteristics.

Electrical Characteristics

It was reasoned that pulp insulated cables would probably be inherently higher in mutual capacitance than similar sizes of paper ribbon cables because, considering the insulated wire itself, in the case of helically applied strip insulation the volume of air beneath the paper is about equal to the volume of the paper itself, while for pulp insulation there is very little air space between the insulation and the wire. This fundamental difference could be somewhat compensated for, however, by the introduction of more air into the spaces between the fibres of the pulp insulating medium than is found in the paper ribbon itself, but it was not expected that it would entirely neutralize the effect of lack of air space next to the wire. It was appreciated, however, that the aim should be to get as low density insulation as possible still consistent with obtaining a continuous, flexible and strong covering on the wire and emphasis was placed on this phase from the start of the development.

The very first experimental cables manufactured compared favorably in mutual capacitance with corresponding sizes of strip paper cables. The wire was insulated in a manner resulting in an apparently well centered, round insulation and the covering was low in weight of fibre per unit volume. The insulation after being formed around the wire was quickly dried in a hot tube resulting in less shrinkage and tightening down around the wire while the moisture was being driven out than if slowly dried. The insulation was unsatisfactory, however,

from a continuity and tensile strength standpoint and could not be considered as suitable for commercial cable.

Special effort was then directed towards producing an insulation better mechanically, with the result that the early commercial cables were satisfactory in this regard but were from 20 to 25 per cent higher in mutual capacitance than the standard ribbon paper cable. This impairment in transmission efficiency was considered prohibitive for cables to be used for interoffice trunks and was definitely objectionable for any class of service. However, the indicated savings in cable first cost warranted continuing the development and over a period of years marked progress has been made in reducing this excess of capacitance and yet retaining an insulation sufficiently strong and

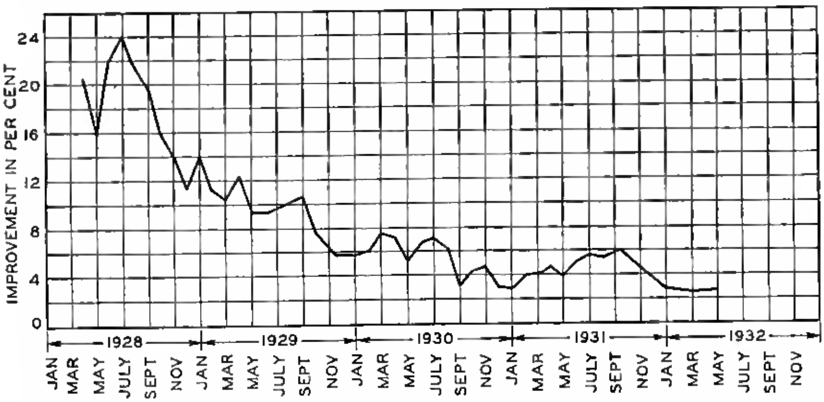

Fig. 8—Curve showing improvement in mutual capacitance since early 1928. Ordinates are percentages by which capacitance of 24 A.W.G. pulp insulated cables exceeds that of ribbon.

flexible to handle reasonably satisfactorily in the fabricating of the cable and installing it in the plant. The attached chart, Fig. 8, shows graphically the progress that has been made in reducing the mutual capacitance of 24 A.W.G. cable since early in the year 1928. Although a substantial improvement has been made in lowering the mutual capacitance to within less than 4 per cent of the corresponding ribbon paper cable, a further reduction would have considerable value warranting more effort in that direction. For 26 A.W.G. cable the excess in capacitance is even less than for 24 A.W.G. and furthermore it is not so objectionable from a transmission standpoint as in the case of the larger gauge.

The principal factors which have brought about this reduction in capacitance are improvements in the treatment of the pulp itself, refinements in machinery operation to permit the use of a lower

density covering on the wire, the more rapid drying out of the moisture from the pulp resulting in less shrinkage of the insulation on the conductors and the producing of more nearly round and better centered insulation. Of these factors perhaps the one having the greatest effect on lowering the mutual capacitance was that of improving the out of roundness of the insulated conductors. In studying this phase of the problem, advantage was taken of the effect of flatness of the insulation, on the component parts which make up the mutual capacitance. The mutual capacitance of a pair of wires is composed of the direct capacitance between the two wires augmented by a series arrangement of two other direct capacitances, one from each of the two wires to the grounded group consisting of all other wires and sheath. As two wires with oval shape insulation are twisted, there is a

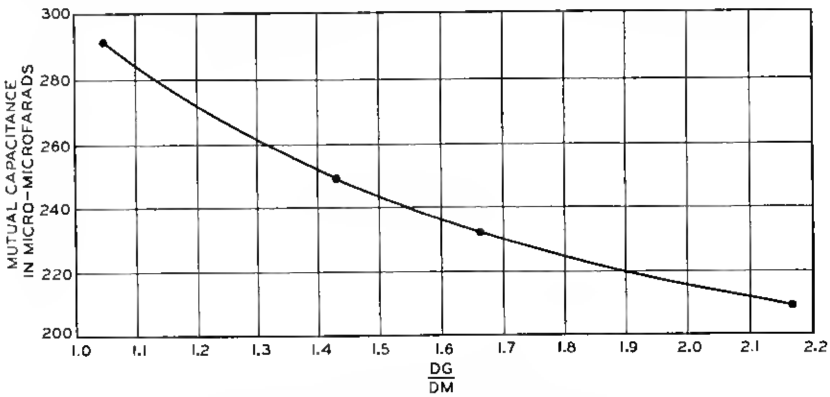

Fig. 9—Curve showing mutual capacitance versus direct capacitance to ground divided by direct capacitance to mate.

decided tendency for two flat sides to stay together resulting in the average separation of wire and mate being less than where circular sections are involved. To determine accurately the degree of out of roundness representing the average condition throughout a length of cable by mechanical means is next to impossible, whereas the direct capacitance between wire and mate automatically integrates this condition. Measurements therefore are made of the component direct capacitances and their ratio used as a sensitive indicator of the effect of flatness of the insulation on the mutual capacitance. By using the ratio of capacitances the cable length error is eliminated and accurate determination can readily be made on short lengths of cable.

As illustrative of the above relation there are given in the following table and curve, Fig. 9, data which were obtained on four short

lengths of pulp insulated cables which so far as was known differed only as regards the lack of symmetry of the insulation.

MUTUAL CAPACITANCE VS. $\left\{\frac{\text{DIRECT CAPACITANCE TO GROUND}}{\text{DIRECT CAPACITANCE TO MATE}}\right.$
AVERAGE VALUE IN M.M.F.

Sample	Mut.	D_M	D_G	D_G/D_M
1	292	187	201	1.07
2	250	144	207	1.42
3	233	126	209	1.66
4	206	101	221	2.19

The alternating current mutual conductance follows the trend of the capacitance, resulting in the ratio of conductance to capacitance at a frequency of 900 cycles per second being somewhat higher than the standard ribbon paper cable, but not of a magnitude such as to introduce any serious transmission loss for these fine gauge circuits. The direct current insulation resistance is of the same order as that of strip paper cables.

The dielectric strength of the insulation is ample, being somewhat higher on the average than that of similar strip paper cables. A rather extensive series of mechanical tests comparing pulp and ribbon types of insulated cable under controlled conditions simulating those met with in actual installation, showed that the pulp insulated cables remained superior to the ribbon cables as regards dielectric strength but that under extreme loads they would not withstand quite as much stretch as the ribbon insulated cable without mechanical damage to the insulation.

Installation Features

No new features are involved in installing pulp insulated cable except in the splicing of the conductors after the lengths as supplied from the factory have been placed in position in the plant. This operation, however, is a considerable factor in the total time of the installation procedure because in a not unusual run of a mile of an 1818 pair cable, there may be as many as 40,000 joints to be made involving the stripping of twice that number of ends of insulated wire preparatory to joining the copper conductors.

Immediately upon removing the lead sheath from the ends of the cables thus exposing the dry insulation to the atmosphere, absorption of moisture rapidly takes place. It is customary, therefore, to boil out the ends of cable with paraffin wax before starting the splicing operation. With strip insulation this wax also aids in preventing the

insulation from unfurling. It was found that even the most flexible pulp insulation so far produced, when impregnated with unmodified paraffin would not withstand satisfactorily the handling incident to splicing at low temperatures. A softer and more lubricating type of compound is required and a suitable combination has been found by adding paraffin oil to the paraffin wax. Different proportions of oil and wax are used depending upon the temperature at the time of installation and the compounding is done at the point of splicing. At an atmospheric temperature of about 75° F. no oil is required and below 10° F. about half oil and half wax makes a suitable compound with proportionate amounts of oil for intermediate temperatures.

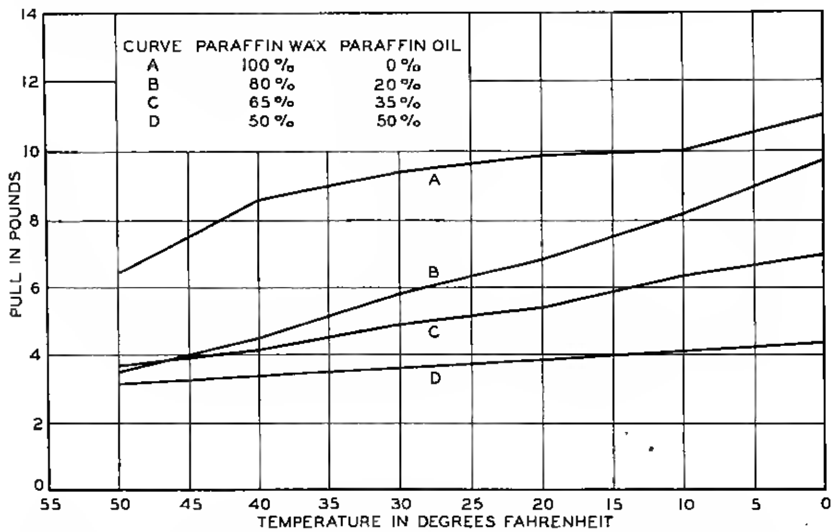

Fig. 10—Curve showing effect of temperature on pull required to strip insulation impregnated with various wax and oil mixtures.

In starting to make a splice, the insulated conductors are brought together in proper position, given a sharp crossover, the wires cut off so as to give several inches of free end, the insulation broken at the crossover and then stripped off the ends. Thus the ideal insulation is one which when waxed, can readily be parted at the crossover and when broken will slip freely along the wire, yet will withstand considerable bending and folding at other places in the splice without breaking. Pulp insulation tends to cling to the conductor somewhat more than a paper tube of strip insulation and although there is considerable variation in this characteristic in the product as now manufactured, it is sufficiently under control so that with a small amount of experience a splicer applying his usual technique is able to handle

even 26 A.W.G. wire with little breaking of the conductors. Fig. 10 shows the stripping characteristics of typical pulp insulation on 24 A.W.G. conductors impregnated with compounds of different proportions of paraffin wax and oil. The pull required to strip the insulation from a few inches of wire is plotted against atmospheric temperature and shows the benefit of the higher percentage of oil particularly at the lower temperatures. There is, of course, with pulp no raveling of the insulation, and the cotton sleeves which are used to insulate the joint slip over the ends of the wires rather more readily than for the spirally applied paper. Thus the overall time required for joining a given number of pairs is practically the same for the two types of insulation.

An unbleached pulp is used and the natural brownish color of the Kraft stock results in less sharp color distinction for the different groupings of pairs than where ribbon insulation is used. However, by simplifying the color code so as to require only red, blue, and green, besides the natural color, sufficient contrast in the shades is obtained so that there is no difficulty in distinguishing colors in the splicing operation.

Possible Applications

This work was undertaken primarily to develop an insulation for use in exchange area cables and efforts have been confined largely to this phase of the study. It is possible to vary the characteristics widely by changes in the raw materials, process and subsequent treatment and other fields of use are being considered.

Pulp insulation is being used as sleeving for lead-in wires in some apparatus at the present time. For this purpose the insulation is made on 19 A.W.G. wire, stripped from the wire and cut in short lengths. It has proved quite superior to the old paper sleeves rolled by hand over mandrels.

Preliminary tests have indicated that there may be a field for use for this type of insulation with certain modifications for switchboard wiring, terminating cables and some kinds of coils.

Economies

Preliminary cost figures indicated that this process offered the possibility of a considerable saving over the ribbon process. These predictions have been verified by actual machine operation extending over a period of more than three years. The savings are made possible by the low cost of Kraft pulp as compared with manila paper and by the elimination of the intermediate paper making, paper slitting and handling operations.

Conclusions

A new type of insulated wire which is considerably cheaper than paper ribbon insulation has been developed. The insulation is formed from paper pulp directly on the conductor by a special type of paper making equipment. This equipment is not critical to the kind of pulp used but for the purposes of durability, strength and economy a Kraft wood pulp has been used in telephone cables. The process has progressed through the development stage and is now in continuous operation in the commercial production of all the principal exchange area cables of 24 and 26 A.W.G. conductors used in the Bell System. Thousands of miles of lead encased pulp insulated cables, ranging in size from the smallest consisting of 11 pairs to the largest consisting of 1818 pairs, are now giving satisfactory service and because of the substantial economies which the construction promises for the finer wire cables, attention is being directed toward its possible application to larger gauge cable conductors and to its use as an insulating medium for other electrical circuits.